

# The Electromyogram of the Posterior Cricoarytenoid Muscle is a Possible Trigger for the Phrenic Pacemaker

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## Abstract

*Voluntary direct control of the breathing pattern by patients equipped with a phrenic pacemaker may be beneficial in avoiding interference of inspiration with speech and swallowing. As a step towards this goal this work therefore investigated the electromyogram (EMG) of the posterior cricoarytenoid (posticus) muscle as a trigger signal for the FES-induced inspiration. The posticus muscle opens the vocal fold during the inspiration. It is still accessible for most patients with high spinal cord injury and therefore has a high potential as a source for a voluntary trigger signal.*

*In an animal trial on sheep four types of electrodes were tested in measurements of the posticus EMG over periods up to 200 days. The breathing effort was recorded synchronously over a piezoelectric belt.*

*It was shown that the EMG of the posticus muscle may well serve as a trigger for a phrenic pacemaker in a clinical situation: The developed electrodes survived the 200 day period in vivo, the resulting EMG signals proved useful for triggering purposes.*

## 1. Introduction

Stimulation of the phrenic nerve has been successfully used to restore active breathing for patients in patients with high spinal cord injury [1; 6; 9].

All available pacing systems impose a fixed respiration pattern onto the patient which does not adapt to the actual need [2; 5; 8]. To make up for changing oxygen need and to improve speech and swallowing it is desirable to provide patients with a means to control the onset of inspiration voluntarily.

The posticus muscle is located on the larynx. It opens the vocal fold during inspiration. It is a promising source of a control signal for two reasons: (1) Most patients with high spinal cord injuries still can control it and (2) a correlation between the EMG signal of the posticus muscle and the voluntary respiration has already been established [3; 10]. The aim of this work was

therefore to develop the technical means to derive a useful trigger signal from the activity of this muscle.

## 2. Methods

Four types of EMG electrodes were developed and manufactured in our department: (1) Single ring-shaped electrode made of stranded stainless steel wire, (2) Single ball tipped electrode with a diameter of one millimetre made of platinum, (3) Triple ring-shaped electrode made of stainless steel mounted on a silicone patch, and (4) Triple ball tipped electrode mounted on a silicone patch. The electrodes were implanted bilaterally in four sheep, one for each type of electrode (Fig.1). The connection to the external measurement equipment was established over transcutaneous connectors. Additionally to the EMG the electrical impedance across the larynx was measured in order to study its use as a trigger signal. A piezo breathing belt was used to record movements of the abdominal wall as a measure for the timing of voluntary breathing. The signal amplifiers were all developed and built in our department.

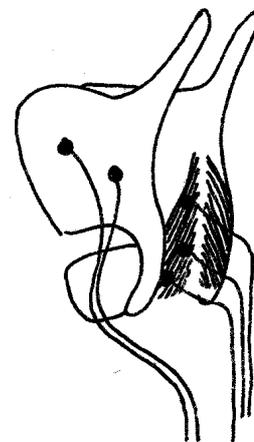


Fig. 1: Schematic drawing of sheep larynx in left posterior oblique view. 3 Electrodes were attached to each PCA muscle for EMG measurement and 2 electrodes thyroid cartilage on both sides for impedance measurement (total 10 electrodes per sheep).

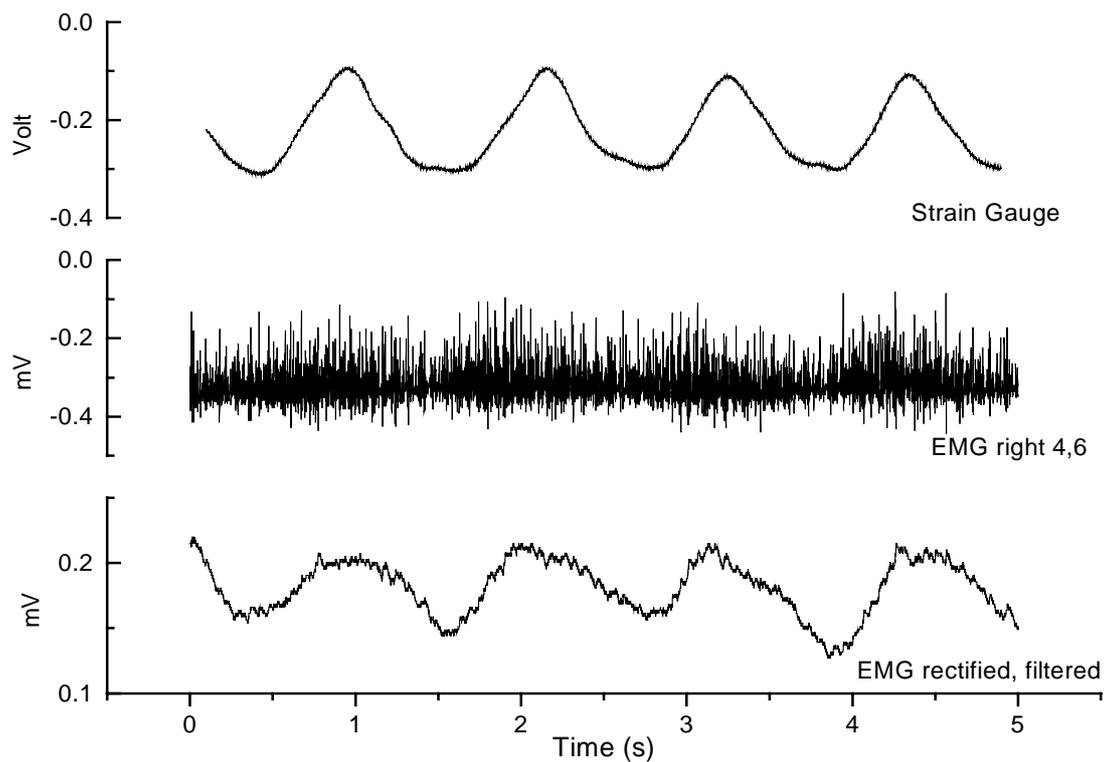


Fig. 2: Respiration effort measured over a piezoelectric breathing belt (upper trace), PCA EMG picked up over implanted electrodes (raw signal, middle trace), and filtered and integrated EMG (lower trace) recorded simultaneously 200 days after electrode implantation.

These signals were synchronously digitized, displayed and stored on a laptop-PC using a plug-in analog-to-digital converter card and software. A detailed description of the equipment may be found in [7]. Measurements were continued in frequent follow-up trials for a period of 200 days postoperatively.

Every follow up trial consisted of an initial measurement of electrode impedance in order to document the long-term-stability of the electrodes and to detect possible electrode failure. After that the EMG of the posticus muscle was measured during situations like standing still, walking, chewing and swallowing in order to estimate possible influences on the signal quality. The stored signals were reviewed on the computer after the final investigation. In a number of trials an analog filter and integrator was used to derive the amplitude from the raw EMG (see Fig.2).

### 3. Results

All electrodes remained electrically stable throughout the experiment. The leads of the electrodes type (1) and (2) however broke within 73 and 31 days postoperatively. This was caused by material fatigue due to prolonged and frequent bending of the electrode lead within the muscle. The electrode types (3) and (4) were of improved construction and survived the complete experiment period of 200 days without signs of material

fatigue. The results of the electrode impedance investigation may be found in [4] in greater detail.

The PCA EMG recordings were analyzed in amplitude and frequency. The peak to peak voltage of the EMG at respiration varied between 0.2 and 0.6 mV. An analysis of the EMG in the frequency domain was performed. The calculated power spectral density showed the relevant frequency components to be in the range from 20 to 500 Hz.

Fig. 2 shows a measurement of the EMG synchronous to the breathing activity taken 200 days postoperatively. The amplitude of the EMG is markedly increased during the inspiration phase of the breathing cycle. The EMG of the posticus muscle and the inspiration signal from the breathing belt corresponded very closely over the complete period of observation.

The artifacts caused by changes in electrode – tissue coupling during swallowing and movements of the neck were studied in their frequency distribution and compared to the posticus EMG. They caused signal components below the frequency band of the EMG. They can therefore be eliminated by the use of high pass filtering. Crosstalk from the EMG of neighboring muscles however was encountered in the same spectral region as the signal of interest, as would be expected. These signal components could therefore not be eliminated due to their inherent similarity to the posticus EMG.

The electric impedance proved useless as a possible trigger signal: Even smallest movements of the animal caused artifacts many times bigger than the signal of interest. The impedance measurements were therefore not continued throughout the trial period after some initial experiments.

#### 4. Discussion

The posticus EMG as it was measured during this study shows a clear correlation to the breathing activity, as could be expected from the literature [3]. After electrode lead failure due to material weakness in the first two animals electrodes of improved design survived the complete measurement period without signs of deterioration. We therefore conclude that the posticus EMG is a possible source of a trigger signal for the phrenic pacemaker.

To reduce the amount of scar tissue and to ease implantation, further work is necessary to improve and miniaturize the electrode design before thinking about use of this principle in humans. Also the differences in anatomy and the effect of the implantation on human phonation has to be considered.

The raw EMG was filtered and integrated in some experiments using analog equipment to derive the amplitude information shown in the bottom trace of Fig.2. Additional work will be necessary to develop sufficient signal processing that assures stable triggering during everyday use of the system. To guarantee reliable operation additional safety precautions will have to be introduced.

#### 5. Conclusion

In this 200 day animal trial it was shown that the EMG of the posticus muscle is a possible source of a trigger signal for the phrenic pacemaker. During the complete postoperative period useful EMG signals were recorded that resembled the breathing activity very well. Artifacts from electrode movements cause frequency components away from the EMG bandwidth. They may therefore be suppressed by high pass filtering. The problem of the crosstalk from surrounding muscles still remains to be resolved. Further miniaturization of the pick-up electrodes will be necessary before the use of this method in humans can be considered.

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